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Soybean (*Glycine max* (L.) Merr.) cultivar tolerance to sulfentrazone☆

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Abstract

Sulfentrazone has excellent soil activity on many small-seeded broadleaf weeds, however, soybean injury in field experiments has been noted under certain environmental conditions. Injury levels in these field experiments have appeared to differ in severity among soybean cultivars. Growth chamber studies were initiated with the objective of examining the suspected differences in tolerance among soybean cultivars. Over 40 soybean cultivars, selected from the USDA Soybean Germplasm Collection, were tested for tolerance to sulfentrazone. The soybean cultivars were grown under constant conditions in a growth chamber in a soil mix treated with sulfentrazone at 0.28 kg ai ha^{-1} preemergence. Ratings of plant injury and measurement of height and biomass reduction were made 14 days after treatment and compared to the respective untreated check plants of each cultivar. Notable differences in tolerance to sulfentrazone across the cultivars were observed. The cultivars were divided into three groups based on plant response and classified as having either high, medium, or low tolerance to sulfentrazone. Results of this study suggest that cultivar selection may lower the risk of early season injury to soybean and potential yield reductions.

Keywords: Soybean; Herbicide tolerance; Protoporphyrinogen oxidase; Plant breeding

1. Introduction

Sulfentrazone, a new herbicide developed for use in soybean (*Glycine max* (L.) Merr.) and tobacco (*Nicotiana tobaccum* L.), recently has been introduced into the major soybean producing areas of the Midwest. Sulfentrazone is a member of the aryl triazolinone herbicide family (Theodoridis et al., 1992). Its mode of action is similar to that of the diphenyl ether herbicides in that it inhibits protoporphyrinogen oxidase (PPO) (Nandihalli and Duke, 1993). PPO oxidizes protoporphyrinogen to protoporphyrin IX in the chlorophyll biosynthetic pathway, and it is the buildup of this intermediate material that results in cell membrane disruption and subsequent plant death (Becerril and Duke, 1989a, b). Most susceptible weed species are killed as they emerge from the soil and are exposed to sunlight.

Sulfentrazone exhibits excellent preemergence soil activity and is active on many of the problem small-seeded broadleaf weeds common to soybean production across the Midwest, including common lambsquarters (*Chenopodium album* L.) and the *Amaranthus* spp. complex. Sulfentrazone also suppresses a number of grass species and has value from a weed resistance management standpoint in the control of ALS resistant biotypes of some problem species. For these reasons sulfentrazone often has been applied alone or in combination with other herbicides, such as chlorimuron or clomazone as early pre-plant (EPP), pre-plant incorporated (PPI), or preemergence (PRE) applications in both no-till and conventional tillage soybean production.

Throughout the initial field testing and recent commercialization of sulfentrazone many studies in both field and laboratory, have reported differences in sensitivity of soybean cultivars to sulfentrazone (Dayan et al., 1997; Li et al., 1997; Swantek and Oliver, 1996). More recently, Li et al. (1999) documented differences in sensitivity to soil-applied sulfentrazone among 28 soybean cultivars by the use of seedling growth parameters, such as hypocotyl

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and root length reduction measurements, as well as by field testing. soybean cultivars historically have been shown to have differing responses to many commonly used herbicides. Wax et al. (1976) and De Weese et al. (1989) found that soybean cultivars varied greatly in response to metribuzin and that cultivars could be categorized as either tolerant or sensitive to metribuzin. Others have found soybean cultivar responsed differently to applications of the imidazolinone herbicides, imazaquin, and imazethapyr (Kent et al., 1988; Wixson and Shaw, 1991).

Soybean seedling injury in the field following applications of sulfentrazone is often associated with cool wet soil conditions similar to that of injury from other soil-applied soybean herbicides. Some common symptoms of soybeans injured by sulfentrazone applications include callusing of the hypocotyl arch, and in extreme cases hypocotyl abortion, callusing of the soybean stem at the soil surface, shortened internodal length, speckling or necrosis of leaf tissue, and an overall slowed early season growth rate. The risk of soybean injury from applications of sulfentrazone, as with most soil-applied herbicides, also appears to be linked to adverse environmental conditions that lead to poor soybean growth and development. Slow soybean emergence through cool, wet soils treated with sulfentrazone can increase the risk of seedling injury due to high levels of available sulfentrazone and increased contact time with the herbicide (Wehtje et al., 1995). Sulfentrazone application timings at soybean emergence or just prior to emergence also increase the risk of injury to soybean as compared to earlier applications due to concentrated levels of herbicide in the soybean germination zone. Low soil organic matter content or coarse sandy soils can increase the risk of injury due to lower sulfentrazone adsorption to the soil (Grey et al., 1997).

To date there is limited information available on the mechanisms of soybean tolerance to sulfentrazone, the genetically mediated components of cultivar tolerance to sulfentrazone, and environmental and edaphic conditions associated with soybean injury resulting from applications of sulfentrazone. When environmental conditions conducive to sulfentrazone injury occur, it would be beneficial to producers to have planted the most tolerant cultivars. The objective of this study was to evaluate the sensitivity of selected current cultivars and the major ancestors of current soybean cultivars to preemergence application of sulfentrazone under controlled conditions.

2. Materials and methods

Ancestral soybean cultivars were selected for the sulfentrazone tolerance experiment on the basis of their relative importance of use in soybean breeding programs resulting in modern soybean lines. Gizlice et al. (1994) identified 35 extant ancestors and first progeny of public North American cultivars that account for over 95% of the genes in current soybean cultivars. These ancestral lines, plus selected current cultivars, were tested for tolerance to a soil-applied application of sulfentrazone (Table 1). The soybean cultivars were selected from the USDA Soybean Germplasm Collection, Urbana, IL.

Soybean seeds were planted at a 2 cm depth in plastic 650 ml square containers containing a standard greenhouse soil consisting of a 1 : 1 : 1 mix of soil, torpedo sand, and peat. The pots, each containing six soybean seeds of one cultivar, were placed in a growth chamber[1] in a completely randomized fashion and watered to approximately 60–70% of field water holding capacity to adequately moisten the soil and stimulate the germination of the soybean seed. Formulated sulfentrazone (75 DF) was applied to the soil surface preemergence 1 DAP using a belt driven laboratory sprayer set to deliver 187 l ha^{-1}. Sulfentrazone was applied at the rate of 0.28 kg ai ha^{-1} to the soil surface. The pots were not watered further until after soybean emergence. At emergence each pot was thinned to four plants. Conditions in the growth chamber were maintained on 16 h days, with a daytime temperature of 28°C and night temperature of 23°C. Light was provided by fluorescent tubes and incandescent bulbs at a level of 600 uE m^{-2} s^{-1}. Relative humidity in the growth chamber was maintained between 70–80%. The soybean seedlings were watered and fertilized[2] from above as needed after emergence. The experiment was repeated.

Visual ratings of soybean injury were made 14 DAT compared with the respective untreated plants for each cultivar. Plant height measurements were also taken 14 DAT. Soybean plants were then harvested and above ground dry biomass measurements were made after drying the plants in a mechanical convection oven at 42°C for 72 h. By averaging the visual injury, ratings of injury and height reduction data (% height reduction) together, a growth reduction index (GRI) was created. For example this index would be 0 if no injury or height reduction was observed or 60 if 50% visually observed injury and 70% height reduction was measured. Data from the two experiments displayed no significant differences and were combined for analysis. Injury and height means represent measurements of 12 plants (4 plants, 3 replications × 2 experiments). The GRI data was analyzed using the 'fastclus' procedure with SAS,[3] a method of data analysis which places objects into "clusters" or groups such that all objects within a group have similar

[1] Environmental growth Chambers, Chagrin Falls, OH 44022.

[2] Peters professional soluble plant food (20-20-20), A.H. Hummert Seed Co., 2746 Chouteau Avenue, St. Louis, Mo 63103.

[3] SAS Institute Inc., SAS Campus Drive, Cary, NC 27513.

Table 1
Ancestor and public soybean cultivars used in sulfentrazone tolerance experiment

Cultivar	Maturity group	Origin[a]	% of modern cultivars[b,c]	
			Northern varieties	Southern varieties
Fiskeby V	000	Sweden	0.5	0.0
Manitoba Brown	00	Canada	1.5	0.0
PI 438477	00	Sweden	1.1	0.0
Flambeau	00	Russia	0.9	0.0
Fiskeby III	00	Sweden	0.7	0.0
Mandarin (Ottawa)	0	China	17.2	0.0
Capital	0	China	2.3	0.0
PI 80501	0	—	—	—
Richland	II	China	11.3	0.8
Mukden	II	China	4.9	0.0
Bansei	II	Japan	1.1	0.0
Kanro	II	N. Korea	1.0	0.0
Korean	II	N. Korea	0.7	0.0
Elgin	II	—	—	—
Lincoln	III	China	24.1	2.9
A.K. (Harrow)	III	China	6.8	0.0
Dunfield	III	China	3.5	3.8
Illini	III	China	3.1	0.0
Jogun	III	N. Korea	0.7	0.0
PI 88788	III	China	0.3	0.7
Thorne	III	—	—	—
Perry	IV	China	2.0	2.0
PI 80837	IV	Japan	0.0	2.3
PI 71506	IV	China	0.1	0.3
FC 33243	IV	—	1.1	0.7
Peking	IV	China	0.1	1.1
S-100	V	China	1.7	21.3
Hutchison	V	—	—	—
Ogden	VI	Japan	4.3	6.4
Haberlandt	VI	N. Korea	0.1	2.5
Arksoy	VI	N. Korea	0.0	1.6
Ralsoy	VI	N. Korea	0.0	1.9
FC 31745	VI	—	0.0	1.1
Tracy-M	VI	—	—	—
CNS	VII	China	2.9	24.7
Jackson	VII	—	0.1	10.6
Roanoke	VII	China	0.2	6.5
Ransom	VII	—	—	—
Gasoy 17	VII	—	—	—
Improved Pelican	VIII	—	0.0	1.7
Cobb	VIII	—	—	—
PI 240664	X	—	—	—

[a]Origin given if known.
[b]Describes the relative influence each ancestor cultivar has had in breeding programs used to develop modern cultivars grown in the northern and southern regions of the US (Gizlice et al., 1994).
[c]A dash line indicates those cultivars which are not considered ancestral lines.

characteristics. On the basis of this analysis, the soybean cultivars were grouped together into three different classifications based on their relative tolerance to sulfentrazone.

3. Results and discussion

The soybean cultivars grown under controlled conditions exhibited varying degrees of sensitivity to the preemergence application of sulfentrazone. At the application rate of $0.28\,kg\,ai\,ha^{-1}$, which is comparable or slightly higher than commonly recommended field use rates, differences in plant injury, height, and dry biomass were evident among cultivars (Table 2). Based on these differences it became apparent that some cultivars are highly tolerant to sulfentrazone while others are relatively less tolerant to preemergence applications of sulfentrazone and some are intermediate in response. As a result, the cultivars tested were classified as either having high, medium or low tolerance to sulfentrazone (Table 2). The growth reduction index, or average of the height and visual injury ratings, expressed as a percent of the check plants of each cultivar, was used to classify the cultivars. Those cultivars with a GRI of greater than 40 were classified as cultivars with low tolerance. Those cultivars with GRI values between 11 and 40 were classified as cultivars with medium levels of tolerance. Those cultivars with a GRI value 10 or less were classified as highly tolerant cultivars. A clear distinction between high tolerance and low tolerance to sulfentrazone was not shown in this study, and it appears that some of the cultivars tested show intermediate levels of tolerance to preemergence applications of sulfentrazone. This type of finding is in agreement with what other researchers, both public and private, have concluded (Li et al., 1999; Pioneer Hi-Bred International, Inc., 1998; Walker et al., 1992).

Injury symptoms were similar to those symptoms seen in the field studies and included plant stunting, shortened internode length, and callusing of the hypocotyl arch at the time of soybean emergence. Soybean height reduction ranged from 0–71% and was a better indication of injury then biomass reduction measurements (data not shown) since severely injured plants had a greater mass than untreated plants due to the presence of large amounts callused or waxy, injured tissue.

Among the ancestral cultivars, there was a tendency towards more injury among the southern cultivars (maturity groups > IV), as compared with the earlier maturing more northern varieties (maturity groups < IV). Examples of this include the cultivars like 'Jackson', 'Ogden', 'Roanoke', and 'CNS', all of which make up a considerable amount of the parentage of commonly grown, modern southern varieties. Attempts to definitively link these ancestral cultivars to sensitive modern varieties through soybean breeding records were unsuccessful. Many of the varieties currently used in production have too many common ancestors and it is difficult to quantify just how much influence in terms of specific herbicide tolerance, one ancestral line has had over another. This problem is the focus of ongoing field research around the country. Recent evidence suggests

Table 2
Soybean cultivar response to preemergence application of sulfentrazone

Cultivar tolerance	% Injury[a]	% Height reduction[b]	GRI[c]
Low			
Tracy-M	53	71	62
Gasoy 17	51	68	60
PI 240664	53	66	60
Jackson	48	64	56
Improved Pelican	50	56	53
Ransom	43	60	52
Cobb	40	60	50
Hutcheson	45	47	46
FC 31745	38	52	45
Ogden	33	50	42
Medium			
Roanoke	35	46	40
Korean	40	41	40
Perry	25	38	32
Peking	13	30	22
PI 438477	16	29	22
CNS	17	22	20
Dunfield	20	14	16
Bansei	22	13	16
PI 71506	21	12	16
FC 33243	12	21	16
(Fiskeby V)	17	10	14
Flambeau	18	9	14
Ralsoy	18	8	13
PI 80837	13	11	12
High			
Arksoy	11	10	10
Capital	10	10	10
Haberlandt	18	2	10
PI 180501	11	9	10
Illini	7	12	8
Jogun	14	5	8
S-100	10	7	8
Mukden	6	11	8
Thorne	6	9	8
Fiskeby V	6	5	6
Lincoln	10	0	5
Richland	9	0	4
Kanro	1	5	3
Fiskeby III	5	2	3
PI 88788	5	0	2
A.K. (Harrow)	3	2	2
Manitoba Brown	3	0	2

[a]Visual rating of injury made 14 DAT comparing treated and untreated plants of each cultivar. Expressed as percent injury, and based on general seedling development, leaf chlorosis, and overall plant vigor.
[b]Height measurement taken 14 DAT comparing treated and untreated plants of each cultivar, expressed as % of untreated check.
[c]Growth reduction index (mean of visual injury and height ratings).

that tolerance to sulfentrazone may be controlled by a single gene, with tolerance being dominant over susceptibility (Swantek et al., 1998). It should also be noted that problems have not been confined just to the southern varieties, as injury has been noted with commonly grown northern varieties (Pioneer Hi-Bred International, Inc., 1998).

Many factors can contribute to soybean injury associated with the use of a soil-applied herbicide including poor soybean growing conditions, cool, wet or compacted soils, and timing of the application. However, good management options exist for soybean growers who use sulfentrazone as a part of their overall weed management plan. By avoiding the use of the least tolerant varieties the risk of early season injury and potential yield reduction can be minimized. Frequently, injury symptoms such as those seen in this growth chamber study can be overcome throughout the course of the growing season with no yield penalty if environmental conditions are such that the soybean plants can compensate for reduced stand counts or early stunting.

References

Becerril, J.M., Duke, S.O., 1989a. Acifluorfen effects on intermediates of chlorophyll synthesis in green cucumber cotyledon tissues. Pestic. Biochem. Physiol. 35, 119.

Becerril, J.M., Duke, S.O., 1989b. Protoporphyrin IX content correlates well with activity of photobleaching herbicides. Plant Physiol. 35, 1175.

Dayan, F.E., Weete, J.D., Duke, S.O., Hancock, H.G., 1997. Soybean (*Glycine max*) cultivar differences in response to sulfentrazone. Weed Sci. 45, 634–641.

De Weese, W.W., Wax, L.M., Carlson, W.C., Ciarletta, J.A., 1989. Response of soybean (*Glycine max*) cultivars to metribuzin in field and greenhouse. Weed Tech. 3, 566–572.

Gizlice, Z., Carter Jr., T.E., Burton, J.W., 1994. Genetic base for North American public soybean cultivars released between 1947 and 1988. Crop. Sci. 34, 1143–1151.

Grey, T.L., Walker, R.H., Wehtje, G.R., Hancock, H.G., 1997. Sulfentrazone adsorption and mobility as affected by soil and pH. Weed Sci. Soc. 45, 733–738.

Kent, L.M., Barrentine, W.L., Wills, G.D., 1988. Response of twenty determinate soybean (*Glycine max*) cultivars to imazaquin. Proc. South. Weed Sci. 41, 50.

Li, Z., Walker, R.H., Wehtje, G.R., 1997. Laboratory studies for predicting response of soybean cultivars to sulfentrazone. Proc. South. Weed Sci. Soc. 50, 177–178.

Li, Z., Walker, R.H., Wehtje, G., Hancock, H.G., 1999. Use of seedling growth parameters to classify soybean (*Glycine max*) cultivar sensitivity to sulfentrazone. Weed Tech. 13, 530–535.

Nandihalli, U.B., Duke, S.O., 1993. The porphyrin pathway as a herbicide target site. In: Duke, S.O., Menn, J.J., Plimmer, J.R. (Eds.), Pest Control with Enhanced Environmental Safety, American Chemical Society Symposium Series, Vol. 524, pp. 62–78. American Chemical Society, Washington DC.

Pioneer Hi-Bred International Inc., 1998. Soybean herbicide variety management guide. Pioneer Hi-Bred International, Inc., Des Moines, Iowa, USA.

Swantek, J.M., Oliver, L.R., 1996. Influence of application method on soybean cultivar tolerance to sulfentrazone. Proc. South. Weed Sci. Soc. 49, 194.

Swantek, J.M., Sneller, C.H., Oliver, L.R., 1998. Evaluation of soybean injury from sulfentrazone and inheritance of tolerance. Weed Sci. 46, 271–277.

Theodoridis, G., Baum, J.S., Hotzman, F.W., et al., 1992. Synthesis and herbicidal properties of aryltriazolinones. In: Baker, D.R., Fenyes, J.G., Steffens, J.J. (Eds.), A New Class of Pre- and Post-emergence Herbicides, American Chemical Society Symposium Series, Vol. 504, pp. 135–146. American Chemical Society, Washington, DC.

Walker, R.H., Richburg, J.S., Jones, R.E., 1992. F6285 efficacy as affected by rate and method of application. Proc. South. Weed Sci. Soc. 45, 51.

Wax, L.M., Stoller, E.W., Bernard, R.L., 1976. Differential response of soybean cultivars to metribuzin. Agron. J. 73, 677–679.

Wehtje, G.R., Walker, R.H., Grey, T.L., Spratlan, C.E., 1995. Soil effects of sulfentrazone. Proc. South. Weed Sci. Soc. 48, 224.

Wixson, M.B., Shaw, D.R., 1991. Differential response of soybean (*Glycine max*) cultivars to AC 263-222. Weed Tech. 5, 430–433.